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FLOOD VULNERABILITY OF CRITICAL INFRASTRUCTURES - REVIEW

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ABSTRACT

Flood event is one of the natural disasters that increasingly threaten the safety of the people in an area. Critical infrastructure albeit important, has been shown to be vulnerable to flooding and damages to critical infrastructure element may affect large areas over a longer time period. Critical infrastructures play an important role in functioning of industries and communities and also responding against flooding to reduce their impacts. Critical infrastructures such as hospital, school, road networks and other infrastructures are important during flood event to serve as emergency services. It was found that there is difference in understanding the concept of vulnerability with varying assessments and different view. This paper briefly reviews the concept of vulnerability and discusses on the approach used for flood vulnerability of critical infrastructure by past researchers to identify and fortify the vulnerable critical infrastructure ahead of time reducing the potential damage due to flood. This paper focuses the vulnerability of critical infrastructure during flood event and also describes several approaches with a discussion on the application of the approaches used and the relevance results.

KEYWORDS

Critical Infrastructure, Flood, Vulnerability, Vulnerability of Critical Infrastructure.

1. INTRODUCTION

Flood is a common natural event in places where rain falls in excess. It could be extremely dangerous due to its potential to wipe away the entirety of the area, thus causing extensive damage to life and property. Flood can occur gradually by the minutes or hours; sometimes even in a sudden, without warning due to causes such as cracking of the embankment, spilling or even heavy rain. The catastrophic flood can cause huge damage, destroying villages, towns, farmland and critical infrastructures [1]. Generally, flooding caused great damage to property and physical infrastructure of many affected communities [2]. Depending on the strength and extent, flood has undoubted potential to destroy bridges, damage traffic infrastructure, disrupting communications systems, power supply and many more. Therefore, it is also possible for flood to destroy critical infrastructures that are needed as shelter and emergency relief for flood victims. This makes it difficult to predict the impact and consequences of the flood, particularly to critical infrastructures [1].

Despite the technological development of mankind, societies are increasingly threatened by the natural disaster [1]. Natural disasters such as flood and their impact on people and critical infrastructure cannot be prevented, but prediction and early warning of disasters can be improved for faster and more efficient revitalization of endangered values and goods can be increased. Therefore, it is important to identify and fortify the vulnerable critical infrastructure ahead of time to significantly reduce the potential damage due to flooding. In this regard, this paper gives a brief review of the concept of vulnerability, discussion on the approach used, and the resulting awareness into the vulnerability of critical infrastructure for flooding by past researchers.

2. VULNERABILITY TERMINOLOGY

In assessing the losses caused by natural disaster such as flooding, it is essential to understand the how vulnerable are those affected by the disaster. This means the vulnerability of the people, the land as well as the properties such as infrastructures in the affected areas. The concept of vulnerability can be extracted from the concept of risk caused by disaster that can be interpreted and understood in different ways by different people [3]. Regardless, by understanding the concept of risk, it helps those involved with disaster management to measure and also manage the potential risk of the disaster event.

Risk is the probability of a loss and this depends on three elements, which are hazard, vulnerability and exposure. Risk can be expressed in a mathematical form as:

$$\text{Risk} = \text{Hazard} \times \text{Exposure} \times \text{Vulnerability} \quad (1)$$

Hazard refers to natural disasters that may occur on a random basis. Exposure means the population, infrastructure and environment. It also means the populations that are present during a flood occur.

Vulnerability is an important concept in human-environment research where past researchers have provided admirable reviews of main literature review on the development of the concept of vulnerability [4-6]. In general, the root meaning of vulnerable is "to wound", therefore, vulnerability can be described as "the capacity to be wounded" [7]. Vulnerability refers to the core characteristics of the hazard's receptors (which can be people, infrastructure, economic activities or others), and defines the extent to which these receptors are susceptible to harm from, or unable to cope with hazards [8]. Vulnerability is the potential for loss, but the definition differs in other assessments with different view for geography, sociology or political science [5]. The framework of UN's International Decade of Natural Disaster Reduction (IDNDR), vulnerability assessments are used to determine the potential damage and loss of life from extreme natural events.

In flood risk management, vulnerability is the main construct [9]. Therefore, flood vulnerability is one of the significant components in flood risk management and damage assessment [10]. A group researcher

defined flood vulnerability as the possibility of negative effects such as harm, damage or causalities caused directly or indirectly by floods [11]. Other researcher defined that flood vulnerability as the degree of susceptibility to damage from the flood [12]. When flood physically attacks on people and infrastructure, then the vulnerability of people and infrastructure is based on the degree of harm and damage [13]. Since vulnerability is found to be the main reason of disasters, it seems necessary to develop the perception of the vulnerability [14]. Since vulnerability cannot directly measure; several methods have been proposed to estimate it.

3. CRITICAL INFRASTRUCTURE

Infrastructures is described as the basic facilities, services, and installations needed for the functioning of a community or society such as transportation and communications systems, water and power lines, and public institutions including schools, post offices and prisons. Therefore, infrastructure plays an important role in the daily living life. However, most infrastructures are usually designed using codes and standards based on the historic climate data which is no longer adequate for climate loads experienced by the infrastructure today.

Many definitions of critical infrastructures were found by past researchers [11,15]. The concept of critical infrastructure came into public view around the middle of the last decade of the 20th century, when the US started to acknowledge that is had identified that there were a set of facilities and services that came together to provide the elements that were 'critical' to the running of a country and the well-being of its citizens [16,17]. Critical infrastructure plays a very important role not only for sustaining industries and communities but also in properly responding against natural disaster such as flood to reduce their impacts [18]. According to, critical infrastructure stands for the infrastructure which is essential for the functioning of society, whose failure would seriously affect many people [11].

In addition to the definition, the clear scope of critical infrastructure is also essential [11]. The compounds as critical infrastructure that identified by most researchers are water supply and drainage networks, communication related infrastructures, schools, hospitals, sanitation, transportation, telecommunication, administrative and emergency service buildings and road networks. Therefore, there are group researcher also defined that critical infrastructure includes all networks and buildings that are essential for the functioning of society during the flood event and for the recovery from the flood event [11]. It is considered as critical because an outage of the infrastructure has a serious effect on many people over a long period. In other studies, stated that critical infrastructure includes physical resources, services, information technology facilities, networks and infrastructure assets which, if destroyed by the flood, would have a serious impact on the health, safety or economic of the victims [19].

Until now, the term critical infrastructures has become central in the emergency preparedness work of many nations, but there is yet no entirely accepted definition of the term [20]. According to the documents of the United Nations, critical infrastructure represents the infrastructure that consists of physical and information technology facilities, networks, services and property, which if collapsed or destroyed can have a serious impact on health, safety and economic well-being and effective functioning of government [21]. Therefore, critical infrastructure is very important to be identified early so that it can reduce the impact of the flood.

4. VULNERABILITY ASSESSMENT OF CRITICAL INFRASTRUCTURE

Natural disaster such as flood has increasingly threatened people and their property, critical infrastructure day by day [1]. The impacts of flooding on critical infrastructure can be seen through the understanding of the physical characteristics of the flood, that is, destructiveness that is determined by destructive force and possibility of propagation in the territory. Taking the definition of vulnerability from a study, the vulnerability of critical infrastructure is in strong correlation with the intensity of flooding which affect community in the flooding area [8].

Another group researchers developed a decision support system for identifying critical infrastructure as well as its vulnerability to flood events by applying critically and vulnerability assessments [18]. The decision support system was developed to support emergency agencies and industries to prepare mitigation strategies and plans for preparedness, response and recovery using the critically and vulnerability analyses. The data in forms of questionnaires, interviews and site investigation in terms of technical, social and economic were collected from the affected communities. Critically analysis was based on the dependency of a community or an industry on critical infrastructure in terms of their daily routine activities and it is important to measure the level of inter-relationship between critical infrastructure, industries and communities.

Vulnerability analysis was based on the vulnerability level of each infrastructure based on the varied timeline (before, during and after) of the flood. After the developed decision support system, Bayesian Network Theory was used for calculating probabilities of failure of each component while System Dynamics Simulation method is to simulate the vulnerability assessment of critical infrastructure allied industries and communities. The result can be used for immediate actions to save life, property and environment. Data for disaster impact analysis in term of social, economic and technical aspect can be collected for assistance and improving preparedness against the impact of natural disaster. Additionally, the assessment can help to examine the conditions of critical infrastructures which significant to protect industries and communities.

A study on finding a pattern for the differences of the vulnerability in the urban areas has been conducted by a group researcher [22]. The variables in vulnerability assessment have been used, which is the physical infrastructures including element at risk and intensifying elements. The elements at risk are the old structures are occupied by many people and can be easily covered by flooding. Physical elements consisted of variables of old texture blocks, population concentration, land use and distance to bridges, while intensifying elements are drainage network, water courses and slope that are effective in flood assessment. Analytical Hierarchy Process (AHP) has been used in this study to convert relative variables into ratio scales and getting weights of relative preferences. The relative weights were used as the magnitude of influence of each variable in vulnerability. The equation below is defined as a function of the vulnerability in front of the flood.

$$V = (0.3825P) + (0.2504T) + (0.1596T) + (0.1006B) + (0.641S) + (0.0428D) \quad (2)$$

Where V is vulnerability, P is population concentration, T is old texture blocks, B is distance to bridges, S is the slope and D is drainage network concentration. The result shown in a vulnerability map will indicate which area as very high and low vulnerable towards flood.

Other researchers reported two approaches of flood vulnerability assessment in their study [23]. First was the economic damage that is fundamentally a quantification of the expected or actual damages to a structure expressed in economic terms or through an evaluation of the percentage of the expected loss. While the other approach deals with the physical vulnerability of individual structures and on the estimation of the likelihood of occurrence of physical damages or collapse of a single element such as, building. Empirical method was used based on the analysis of observed consequences which by collection of actual flood damage information from the respondents after the event through interviews, questionnaires and field mapping was used for this study. The main advantage of these methods is the use of real data. However, the results were very much dependent on the respondents' risk perception for the first two approaches of data availability and the methodology for collection method.

On the following year, the vulnerability of critical infrastructure to flood by analysing the vulnerability and coping capacity of infrastructures [24]. The approach is used by using questionnaires survey, interview with 150 selected respondents from each zone and infrastructure analysis. The survey covered in the zone of areas that had experienced heavy damage, medium and light damage. The questionnaires discovered the local community's characteristic and interview in face to face interaction before and after the flood disaster, different coping mechanisms and analysis of infrastructure such as school, roads, hospitals and markets. Risk index is to determine the strength of resilience of the zone. It was calculated with the calculated coping strength of the zone and hazard occurrences using the UNDP (1992) formula:

$$\text{Vulnerability} = \text{Hazard} / \text{Coping Strategies} \quad (3)$$

The results show variations between zones in coping strength and vulnerability which indicates varying local coping capacities. The measurement of vulnerability to flood has helped to identify the capacities of local communities to manage and to overcome emergencies and disaster situations. And also determine the critical infrastructures to flood and thus support their preparedness for disaster situation.

A research of reducing future vulnerability of critical infrastructure to flooding, which was also to build a more resilient society [19]. In order to reduce the flood vulnerability and increase the resilience of the critical infrastructure networks in future, detailed evidence-based analysis and vulnerability assessment is needed. Therefore, methods used were the

storyline approach and CIrcle tool. The storyline method is to analyse the sequence of flood events including the responses of the most relevant actors while CIrcle tool obtains information from the relevant actors about the vulnerability of critical infrastructure and to study cascade effects. Note that these methods needed the responses of relevant actors such as state agencies, local authorities, metrological service, emergency responders and general public before, during and after the flood event. The result from this research help the actors and others to arrange flood defence and mitigation measures, including emergency management plan. It also shows a valuable outline of the locations of critical infrastructures in the flood-prone area in and around the study area and in knowledge on the effects and the impacts on society.

Meanwhile, an assessment in identifying elements at risk, vulnerabilities of the people, determining triggers for vulnerability to flood disaster and to suggest remedial measures for vulnerability reduction in the study area has been done by a group researcher [25]. The data was obtained through questionnaire and interview schedule with total of 60 respondents. Then, literature review was conducted by gathering information from government and non-government departments, agencies, research reports, journal articles, newspapers and electronic databases. The data was analysed with the software of Statistical Product and Service Solution (SPSS) and Microsoft Excel to calculate the frequency and percentage of each variable. Through this study, it can help to identify which area is highly exposed to floods due to its geographical location and physical infrastructures that are weak and cannot use as evacuation centre. it was found that physical infrastructure in the study area is weak due to inadequate construction material and lack of mitigation measures.

In summary, it can be seen that data analysis based on questionnaires, interviews and site investigation has been practised in flood vulnerability assessment for development of their decision support system [18]. This approach was also adopted later by a group of researchers in their flood vulnerability assessment [23-25]. However, the focus of the questionnaires, interviews and site investigation were differing in each study conducted. Some of researcher focused more on economic and physical damages while the others also take into account of dependency of the community or industry on critical infrastructures in preparing for flood events [23,25]. A researcher takes the coping capacity of infrastructures for the study while in other study, gathered data together with literature reviews and analysed by using software to identify physical infrastructures that cannot sustain flood [24,26]. On the other hand, some of researcher also used analysis based on taking responses from the respondent before, during and after flood event [19]. Nevertheless, it shows that post-event study is essential in identifying critical infrastructures in flood prone areas as well as estimating the flood vulnerability on the life and property in that areas.

5. CONCLUSION

There are many methods have been done by past researchers on developing a vulnerability assessment on critical infrastructure during flood event. Each assessment has the similarities such as by interviewing the citizens or giving out questionnaires about the floods. It shows how important is gathering information from affected population. By gathering the information, this can help to identify the infrastructure that is critical during flooding. This is because flood vulnerability assessments conducted has proven that it involves not only the people living or affected by the flood in certain areas, but also the condition of infrastructure in the area especially the critical infrastructure. Thus, with such assessment, flood mitigation plans can include proper or emergent protection methods for safeguarding those important infrastructures.

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